

BERTRAND CURVES IN THREE DIMENSIONAL LIE GROUPS

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ABSTRACT. In this paper, we give the definition of harmonic curvature function some special curves such as helix, slant curves, Mannheim curves and Bertrand curves. Then, we recall the characterizations of helices [8], slant curves (see [19]) and Mannheim curves (see [12]) in three dimensional Lie groups using their harmonic curvature function.

Moreover, we define Bertrand curves in a three dimensional Lie group G with a bi-invariant metric and the main result in this paper is given as (Theorem 3.4): A curve $\alpha : I \subset \mathbb{R} \rightarrow G$ with the Frenet apparatus $\{T, N, B, \kappa, \tau\}$ is a Bertrand curve if and only if

$$\lambda\kappa + \mu\tau H = 1$$

where λ, μ are constants and H is the harmonic curvature function of the curve α .

1. INTRODUCTION

The general theory of curves in a Euclidean space (or more generally in a Riemannian manifolds) have been developed a long time ago and we have a deep knowledge of its local geometry as well as its global geometry. In the theory of curves in Euclidean space, one of the important and interesting problem is characterizations of a regular curve. In the solution of the problem, the curvature functions k_1 (or κ) and k_2 (or τ) of a regular curve have an effective role. For example: if $k_1 = 0 = k_2$, then the curve is a geodesic or if $k_1 = \text{constant} \neq 0$ and $k_2 = 0$, then the curve is a circle with radius $(1/k_1)$, etc. Thus we can determine the shape and size of a regular curve by using its curvatures. Another way in the solution of the problem is the relationship between the Frenet vectors of the curves (see [15]). For instance Bertrand curves:

In the classical differential geometry of curves, J. Bertrand studied curves in Euclidean 3-space whose principal normals are the principal normals of another curve. In (see [3]) he showed that a necessary and sufficient condition for the existence of such a second curve is that a linear relationship with constant coefficients shall exist between the first and second curvatures of the given original curve. In other word, if we denote first and second curvatures of a given curve by k_1 and k_2 respectively, then for $\lambda, \mu \in \mathbb{R}$ we have $\lambda k_1 + \mu k_2 = 1$. Since the time of Bertrand's paper, pairs of curves of this kind have been called *Conjugate Bertrand Curves*, or more commonly *Bertrand Curves* (see [15]).

Date: September 08, 2012.

2000 Mathematics Subject Classification. Primary 53A04; Secondary 22E15.

Key words and phrases. Bertrand curves, Lie groups.

This paper is in final form and no version of it will be submitted for publication elsewhere.

In 1888, *C. Bioche* [4] give a new theorem to obtaining Bertrand curves by using the given two curves C_1 and C_2 in Euclidean 3-space. Later, in 1960, *J. F. Burke* [5] give a theorem related with *Bioche's thorem on Bertrand curves*.

The following properties of Bertrand curves are well known: If two curves have the same principal normals, (i) corresponding points are a fixed distance apart; (ii) the tangents at corresponding points are at a fixed angle. These well known properties of Bertrand curves in Euclidean 3-space was extended by *L. R. Pears* in [21] to Riemannian n -space and found general results for Bertrand curves. When we applying these general result to Euclidean n -space, it is easily find that either k_2 or k_3 is zero; in other words, Bertrand curves in $\mathbb{E}^n (n > 3)$ are degenerate curves. This result is restated by *Matsuda and Yorozu* [18]. They proved that *there is no special Bertrand curves in $E^n (n > 3)$* and they define new kind, which is called $(1, 3)$ -type Bertrand curves in 4-dimensional Euclidean space. Bertrand curves and their characterizations were studied by many authours in Euclidean space as well as in Riemann-Otsuki space, in Minkowski 3- space and Minkowski spacetime (for instance see [1, 2, 10, 14, 16, 22, 23].)

The degenarete semi-Riemannian geometry of Lie group is studied by Çöken and Çiftçi [9]. Moreover, they obtanied a naturally reductive homogeneous semi-Riemannian space using the Lie group. Then Çiftçi [8] defined general helices in three dimensional Lie groups with a bi-invariant metric and obtained a generalization of Lancret's theorem. Also he gave a relation between the geodesics of the so-called cylinders and general helices. Then, Okuyucu et al. [19] defined slant helices in three dimensional Lie groups with a bi-invariant metric and obtained some characterizations using their harmonic curvature function.

Recently, *Izumiya and Takeuchi* [13] have introduced the concept of slant helix in Euclidean 3-space. A slant helix in Euclidean space \mathbb{E}^3 was defined by the property that its principal normal vector field makes a constant angle with a fixed direction. Also, Izumiya and Takeuchi showed that α is a slant helix if and only if the geodesic curvature of spherical image of principal normal indicatrix (N) of a space curve α

$$\sigma_N(s) = \left(\frac{\varkappa^2}{(\varkappa^2 + \tau^2)^{3/2}} \left(\frac{\tau}{\varkappa} \right)' \right) (s)$$

is a constant function .

Harmonic curvature functions were defined earlier by Özdamar and Hacısalıhoğlu [20]. Recently, many studies have been reported on generalized helices and slant helices using the harmonic curvatures in Euclidean spaces and Minkowski spaces [6, 11, 17]. Then, Okuyucu et al. [19] defined slant helices in three dimensional Lie groups with a bi-invariant metric and obtained some characterizations using their harmonic curvature function.

In this paper, first of all, we give the definition of harmonic curvature function some special curves such as helix, slant curves. Then, we recall the characterizations of helices [8], slant curves (see [19]) and Mannheim curves (see [12]) in three dimensional Lie groups using their harmonic curvature function. Moreover, we define Bertrand curves in a three dimensional Lie group G with a bi-invariant

metric and then the main result to this paper is given as (Theorem 3.4): A curve $\alpha : I \subset \mathbb{R} \rightarrow G$ with the Frenet apparatus $\{T, N, B, \kappa, \tau\}$ is a Bertrand curve if and only if

$$\lambda\kappa + \mu\tau H = 1$$

where λ, μ are constants and H is the harmonic curvature function of the curve α .

Note that three dimensional Lie groups admitting bi-invariant metrics are $SO(3), SU^2$ and Abelian Lie groups. So we believe that our characterizations about Bertrand curves will be useful for curves theory in Lie groups.

2. PRELIMINARIES

Let G be a Lie group with a bi-invariant metric $\langle \cdot, \cdot \rangle$ and D be the Levi-Civita connection of Lie group G . If \mathfrak{g} denotes the Lie algebra of G then we know that \mathfrak{g} is isomorphic to $T_e G$ where e is neutral element of G . If $\langle \cdot, \cdot \rangle$ is a bi-invariant metric on G then we have

$$\langle X, [Y, Z] \rangle = \langle [X, Y], Z \rangle \quad (2.1)$$

and

$$D_X Y = \frac{1}{2} [X, Y] \quad (2.2)$$

for all X, Y and $Z \in \mathfrak{g}$.

Let $\alpha : I \subset \mathbb{R} \rightarrow G$ be an arc-lengthed regular curve and $\{X_1, X_2, \dots, X_n\}$ be an orthonormal basis of \mathfrak{g} . In this case, we write that any two vector fields W and Z along the curve α as $W = \sum_{i=1}^n w_i X_i$ and $Z = \sum_{i=1}^n z_i X_i$ where $w_i : I \rightarrow \mathbb{R}$ and $z_i : I \rightarrow \mathbb{R}$ are smooth functions. Also the Lie bracket of two vector fields W and Z is given

$$[W, Z] = \sum_{i=1}^n w_i z_i [X_i, X_j]$$

and the covariant derivative of W along the curve α with the notation $D_{\alpha'} W$ is given as follows

$$D_{\alpha'} W = \dot{W} + \frac{1}{2} [T, W] \quad (2.3)$$

where $T = \alpha'$ and $\dot{W} = \sum_{i=1}^n \dot{w}_i X_i$ or $\dot{W} = \sum_{i=1}^n \frac{dw}{dt} X_i$. Note that if W is the left-invariant vector field to the curve α then $\dot{W} = 0$ (see for details [7]).

Let G be a three dimensional Lie group and (T, N, B, κ, τ) denote the Frenet apparatus of the curve α . Then the Serret-Frenet formulas of the curve α satisfies:

$$D_T T = \kappa N, \quad D_T N = -\kappa T + \tau B, \quad D_T B = -\tau N$$

where D is Levi-Civita connection of Lie group G and $\kappa = \|\dot{T}\|$.

Definition 2.1. Let $\alpha : I \subset \mathbb{R} \rightarrow G$ be a parametrized curve. Then α is called a *general helix* if it makes a constant angle with a left-invariant vector field X . That is,

$$\langle T(s), X \rangle = \cos \theta \text{ for all } s \in I,$$

for the left-invariant vector field $X \in g$ is unit length and θ is a constant angle between X and T , which is the tangent vector field of the curve α (see [8]).

Definition 2.2. Let $\alpha : I \subset \mathbb{R} \rightarrow G$ be a parametrized curve with the Frenet apparatus (T, N, B, κ, τ) then

$$\tau_G = \frac{1}{2} \langle [T, N], B \rangle \quad (2.4)$$

or

$$\tau_G = \frac{1}{2\kappa^2\tau} \langle \ddot{T}, [\dot{T}, \dot{T}] \rangle + \frac{1}{4\kappa^2\tau} \|[\dot{T}, \dot{T}]\|^2$$

(see [8]).

Definition 2.3. Let $\alpha : I \subset \mathbb{R} \rightarrow G$ be an arc length parametrized curve. Then α is called a *slant helix* if its principal normal vector field makes a constant angle with a left-invariant vector field X which is unit length. That is,

$$\langle N(s), X \rangle = \cos \theta \text{ for all } s \in I,$$

where $\theta \neq \frac{\pi}{2}$ is a constant angle between X and N which is the principal normal vector field of the curve α (see [19]).

Definition 2.4. Let $\alpha : I \subset \mathbb{R} \rightarrow G$ be an arc length parametrized curve with the Frenet apparatus $\{T, N, B, \kappa, \tau\}$. Then the *harmonic curvature function* of the curve α is defined by

$$H = \frac{\tau - \tau_G}{\kappa}$$

where $\tau_G = \frac{1}{2} \langle [T, N], B \rangle$ (see [19]).

Theorem 2.5. Let $\alpha : I \subset \mathbb{R} \rightarrow G$ be a parametrized curve with the Frenet apparatus (T, N, B, κ, τ) . If the curve α is a general helix, if and only if

$$\tau = c\kappa + \tau_G$$

where c is a constant (see [8]) or using the definition of the harmonic curvature function of the curve α (see [19]) is constant function.

Theorem 2.6. Let $\alpha : I \subset \mathbb{R} \rightarrow G$ be a parametrized curve with the Frenet apparatus (T, N, B, κ, τ) . If the curve α is a general helix, if and only if the harmonic curvature function of the curve α is a constant function.

Proof. It is obvious using the Definition 2.4 and Theorem 2.1. \square

Theorem 2.7. Let $\alpha : I \subset \mathbb{R} \rightarrow G$ be a unit speed curve with the Frenet apparatus (T, N, B, κ, τ) . Then α is a slant helix if and only if

$$\sigma_N = \frac{\kappa(1 + H^2)^{\frac{3}{2}}}{H} = \tan \theta$$

is a constant where H is a harmonic curvature function of the curve α and $\theta \neq \frac{\pi}{2}$ is a constant (see [19]).

Theorem 2.8. *Let $\alpha : I \subset \mathbb{R} \rightarrow G$ be a parametrized curve with arc length parameter s and the Frenet apparatus (T, N, B, κ, τ) . Then, α is Mannheim curve if and only if*

$$\lambda \kappa (1 + H^2) = 1, \text{ for all } s \in I \quad (2.5)$$

where λ is constant and H is the harmonic curvature function of the curve α (see [12]).

Theorem 2.9. *Let $\alpha : I \subset \mathbb{R} \rightarrow G$ be a parametrized curve with arc length parameter s . Then β is the Mannheim partner curve of α if and only if the curvature κ_β and the torsion τ_β of β satisfy the following equation*

$$\frac{d\kappa_\beta H_\beta}{d\bar{s}} = \frac{\kappa_\beta}{\mu} (1 + \mu^2 \kappa_\beta^2 H_\beta^2)$$

where μ is constant and H_β is the harmonic curvature function of the curve β .

3. BERTRAND CURVES IN A THREE DIMENSIONAL LIE GROUP

In this section, we define Bertrand curves and their characterizations are given in a three dimensional Lie group G with a bi-invariant metric $\langle \cdot, \cdot \rangle$. Also we give some characterizations of Bertrand curves using the special cases of G .

Definition 3.1. A curve α in 3-dimensional Lie group G is a *Bertrand curve* if there exists a special curve β in 3-dimensional Lie group G such that principal normal vector field of α is linearly dependent principal normal vector field of β at corresponding point under ψ which is bijection from α to β . In this case β is called the *Bertrand mate curve* of α and (α, β) is called *Bertrand curve couple*.

The curve $\alpha : I \subset \mathbb{R} \rightarrow G$ in 3-dimensional Lie group G is parametrized by the arc-length parameter s and from the Definition 3.1 Bertrand mate curve of α is given $\beta : \bar{I} \subset \mathbb{R} \rightarrow G$ in 3-dimensional Lie group G with the help of Figure 1 such that

Figure1:Bertrand curve couple (α, β)

$$\beta(s) = \alpha(s) + \lambda(s) N(s), \quad s \in I$$

where λ is a smooth function on I and N is the principal normal vector field of α . We should remark that the parameter s generally is not an arc-length parameter of β . So, we define the arc-length parameter of the curve β by

$$\bar{s} = \psi(s) = \int_0^s \left\| \frac{d\beta(s)}{ds} \right\| ds$$

where $\psi : I \rightarrow \bar{I}$ is a smooth function and holds the following equality

$$\psi'(s) = \kappa H \sqrt{\lambda^2 + \mu^2} \quad (3.1)$$

for $s \in I$.

Proposition 3.2. *Let $\alpha : I \subset \mathbb{R} \rightarrow G$ be an arc length parametrized curve with the Frenet apparatus $\{T, N, B\}$. Then the following equalities*

$$\begin{aligned} [T, N] &= \langle [T, N], B \rangle B = 2\tau_G B \\ [T, B] &= \langle [T, B], N \rangle N = -2\tau_G N \end{aligned}$$

hold [19].

Theorem 3.3. *Let $\alpha : I \subset \mathbb{R} \rightarrow G$ and $\beta : \bar{I} \subset \mathbb{R} \rightarrow G$ be a Bertrand curve couple with arc-length parameter s and \bar{s} , respectively. Then corresponding points are a fixed distance apart for all $s \in I$, that is,*

$$d(\alpha(s), \beta(s)) = \text{constant}, \quad \text{for all } s \in I$$

Proof. From Definition 3.1, we can simply write

$$\beta(s) = \alpha(s) + \lambda(s) N(s) \quad (3.2)$$

Differentiating the Eq. (3.2) with respect to s and using the Eq. (2.3), we get

$$\begin{aligned} \frac{d\beta(\bar{s})}{d\bar{s}} \psi'(s) &= \frac{d\alpha(s)}{ds} + \lambda'(s) N(s) + \lambda(s) \dot{N} \\ &= (1 - \lambda(s) \kappa(s)) T(s) + \lambda'(s) N(s) + \lambda(s) \tau(s) B(s) - \frac{1}{2} [T, N] \end{aligned}$$

and with the help of Proposition 3.2, we obtain

$$\frac{d\beta(\bar{s})}{d\bar{s}} \psi'(s) = (1 - \lambda(s) \kappa(s)) T(s) + \lambda'(s) N(s) + \lambda(s) ((\tau - \tau_G)(s)) B(s)$$

or

$$T_\beta(\bar{s}) = \frac{1}{\psi'(s)} [(1 - \lambda(s) \kappa(s)) T(s) + \lambda'(s) N(s) + \lambda(s) ((\tau - \tau_G)(s)) B(s)].$$

And then, we know that $\{N_\beta(\bar{s}), N(s)\}$ is a linearly dependent set, so we have

$$\begin{aligned} \langle T_\beta(\bar{s}), N_\beta(\bar{s}) \rangle &= \frac{1}{\psi'(s)} \left[(1 - \lambda(s) \kappa(s)) \langle T(s), N_\beta(\bar{s}) \rangle + \lambda'(s) \langle N(s), N_\beta(\bar{s}) \rangle \right. \\ &\quad \left. + \lambda(s) \tau(s) \langle B(s), N_\beta(\bar{s}) \rangle \right] \\ \lambda'(s) &= 0 \end{aligned}$$

that is, $\lambda(s)$ is constant function on I . This completes the proof. \square

Theorem 3.4. *If $\alpha : I \subset \mathbb{R} \rightarrow G$ is a parametrized Bertrand curve with arc length parameter s and the Frenet apparatus (T, N, B, κ, τ) . Then, α satisfy the following equality*

$$\lambda \kappa(s) + \mu \kappa(s) H(s) = 1, \quad \text{for all } s \in I \quad (3.3)$$

where λ, μ are constants and H is the harmonic curvature function of the curve α .

Proof. Let $\alpha : I \subset \mathbb{R} \rightarrow G$ be a parametrized Bertrand curve with arc length parameter s then we can write

$$\beta(s) = \alpha(s) + \lambda N(s)$$

Differentiating the above equality with respect to s and by using the Frenet equations, we get

$$\begin{aligned} \frac{d\beta(\bar{s})}{d\bar{s}}\psi'(s) &= \frac{d\alpha(s)}{ds} + \lambda(s)\dot{N} \\ &= (1 - \lambda(s)\kappa(s))T(s) + \lambda(s)\tau(s)B(s) - \frac{1}{2}[T, N] \end{aligned}$$

and with the help of Proposition 3.2, we obtain

$$T_\beta(\bar{s}) = \frac{(1 - \lambda\kappa(s))}{\psi'(s)}T(s) + \frac{\lambda((\tau - \tau_G)(s))}{\psi'(s)}B(s).$$

As $\{N_\beta(\bar{s}), N(s)\}$ is a linearly dependent set, we can write

$$T_\beta(\bar{s}) = \cos\theta(s)T(s) + \sin\theta(s)B(s) \quad (3.4)$$

where

$$\begin{aligned} \cos\theta(s) &= \frac{(1 - \lambda\kappa(s))}{\psi'(s)}, \\ \sin\theta(s) &= \frac{\lambda((\tau - \tau_G)(s))}{\psi'(s)}. \end{aligned}$$

If we differentiate the Eq. (3.4) and consider $\{N_\beta(\bar{s}), N(s)\}$ is a linearly dependent set we can easily see that θ is a constant function. So, we obtain

$$\frac{\cos\theta}{\sin\theta} = \frac{1 - \lambda\kappa(s)}{\lambda((\tau - \tau_G)(s))}$$

or taking $c = \frac{\cos\theta}{\sin\theta}$, we get

$$\lambda\kappa(s) + c\lambda((\tau - \tau_G)(s)) = 1.$$

Then denoting $\mu = c\lambda = \text{costant}$ and using the Definition 2.4, we have

$$\lambda\kappa(s) + \mu\kappa(s)H(s) = 1, \text{ for all } s \in I$$

which completes the proof. \square

Corollary 3.5. *The measure of the angle between the tangent vector fields of the Bertrand curve couple (α, β) is constant.*

Proof. It is obvious from the proof of above Theorem. \square

Remark 3.6. It is unknown whether the reverse of the above Theorem. Because, for the proof of the reverse we must consider a special Frenet curve $\beta(s) = \alpha(s) + \lambda N(s)$ in its proof. So, we give the following Theorem.

Theorem 3.7. *Let $\alpha : I \subset \mathbb{R} \rightarrow G$ be a parametrized Bertrand curve whose curvature functions κ and harmonic curvature function H of the curve α satisfy $\lambda\kappa(s) + \mu\kappa(s)H(s) = 1$, for all $s \in I$. If the curve β given by $\beta(s) = \alpha(s) + \lambda N(s)$ for all $s \in I$ is a special Frenet curve, then (α, β) is the Bertrand curve couple.*

Proof. Let $\alpha : I \subset \mathbb{R} \rightarrow G$ be a parametrized Bertrand curve whose curvature function κ and harmonic curvature function H of the curve α satisfy $\lambda\kappa(s) + \mu\kappa(s)H(s) = 1$ for all $s \in I$. If the curve β given by $\beta(s) = \alpha(s) + \lambda N(s)$ for all $s \in I$ is a special Frenet curve, then differentiating this equality with respect to s and by using the Eq. (3.1) with the equation $\lambda\kappa(s) + \mu\kappa(s)H(s) = 1$, we have

$$T_\beta(\bar{s}) = \frac{\mu}{\sqrt{\lambda^2 + \mu^2}}T(s) + \frac{\lambda}{\sqrt{\lambda^2 + \mu^2}}B(s). \quad (3.5)$$

Then, if we differentiate the last equation with respect to s and by using the Frenet formulas we obtain

$$\kappa_\beta(\bar{s})N_\beta(\bar{s})\psi'(s) = \frac{\kappa(s)}{\sqrt{\lambda^2 + \mu^2}}(\mu - \lambda H(s))N(s). \quad (3.6)$$

Thus, for each $s \in I$, the vector field $N_\beta(\bar{s})$ of β is linearly dependent the vector field $N(s)$ of α at corresponding point under the bijection from α to β . This completes the proof. \square

Proposition 3.8. *Let $\alpha : I \subset \mathbb{R} \rightarrow G$ be an arc-lengthed Bertrand curve with the Frenet vector fields $\{T, N, B\}$ and $\beta : \bar{I} \subset \mathbb{R} \rightarrow G$ be a Bertrand mate of α with the Frenet vector fields $\{T_\beta, N_\beta, B_\beta\}$. Then $\tau_{G_\beta} = \tau_G$ for the curves α and β where $\tau_G = \frac{1}{2} \langle [T, N], B \rangle$ and $\tau_{G_\beta} = \frac{1}{2} \langle [T_\beta, N_\beta], B_\beta \rangle$.*

Proof. Let $\alpha : I \subset \mathbb{R} \rightarrow G$ be an arc-lengthed Bertrand curve with the Frenet vector fields $\{T, N, B\}$ and $\beta : \bar{I} \subset \mathbb{R} \rightarrow G$ be a Bertrand mate of α with the Frenet vector fields $\{T_\beta, N_\beta, B_\beta\}$. From the Eq. (3.5) and considering $N_\beta = \mp N$ we have

$$B_\beta(\bar{s}) = -\frac{\lambda}{\sqrt{\lambda^2 + \mu^2}}T(s) + \frac{\mu}{\sqrt{\lambda^2 + \mu^2}}B(s). \quad (3.7)$$

Since $\tau_{G_\beta} = \frac{1}{2} \langle [T_\beta, N_\beta], B_\beta \rangle$, using the equalities of the Frenet vector fields T_β, N_β and B_β we obtain $\tau_{G_\beta} = \tau_G$. Which completes the proof. \square

Theorem 3.9. *Let $\alpha : I \subset \mathbb{R} \rightarrow G$ be a parametrized Bertrand curve with curvature functions κ, τ and $\beta : \bar{I} \subset \mathbb{R} \rightarrow G$ be a Bertrand mate of α with curvatures functions κ_β, τ_β . Then the relations between these curvature functions are*

$$\kappa_\beta(\bar{s}) = \frac{\mu\kappa(s) - \lambda\kappa(s)H(s)}{(\lambda^2 + \mu^2)H(s)}, \quad (3.8)$$

$$\tau_\beta(\bar{s}) = \frac{\lambda\kappa(s) + \mu\kappa(s)H(s)}{(\lambda^2 + \mu^2)H(s)} + \tau_G \quad (3.9)$$

Proof. If we take the norm of the Eq. (3.6) and use the Eq. (3.1), we get the Eq. (3.8). Then differentiating the Eq. (3.7) and using the Frenet formulas, we have

$$\begin{aligned} \dot{B}_\beta(\bar{s})\psi'(s) &= -\frac{\lambda}{\sqrt{\lambda^2 + \mu^2}}\dot{T}(s) + \frac{\mu}{\sqrt{\lambda^2 + \mu^2}}\dot{B}(s), \\ &= -\frac{\lambda}{\sqrt{\lambda^2 + \mu^2}}\kappa(s)N(s) + \frac{\mu}{\sqrt{\lambda^2 + \mu^2}}\left(-\tau(s)N(s) - \frac{1}{2}[T, B]\right) \end{aligned}$$

In the above equality, using the Eq. (3.1) and the Proposition 3.2, we get

$$(\tau_\beta - \tau_{G\beta}) N_\beta(\bar{s}) = \frac{1}{\kappa H (\lambda^2 + \mu^2)} (\lambda \kappa + \mu \kappa H) N(s).$$

If we take the norm of the last equation and use the Proposition 3.8, we get the Eq. (3.9). Which completes the proof. \square

Theorem 3.10. *Let $\alpha : I \subset \mathbb{R} \rightarrow G$ be a parametrized curve with Frenet apparatus $\{T, N, B, \kappa, \tau\}$ and $\beta : \bar{I} \subset \mathbb{R} \rightarrow G$ be a curve with Frenet apparatus $\{T_\beta, N_\beta, B_\beta, \kappa_\beta, \tau_\beta\}$. If (α, β) is a Bertrand curve couple then $\kappa \kappa_\beta H H_\beta$ is a constant function.*

Proof. We assume that (α, β) is a Bertrand curve couple. Then we can write

$$\alpha(s) = \beta(s) - \lambda(s) N_\beta(\bar{s}). \quad (3.10)$$

If we use the similar method in the proof of Theorem 3.4 and consider the Eq. (3.10), then we can easily see that $\kappa \kappa_\beta H H_\beta$ is a constant function. \square

Theorem 3.11. *Let $\alpha : I \subset \mathbb{R} \rightarrow G$ be a parametrized Bertrand curve with Frenet apparatus $\{T, N, B, \kappa, \tau\}$ and $\beta : \bar{I} \subset \mathbb{R} \rightarrow G$ be a Bertrand mate of the curve α with Frenet apparatus $\{T_\beta, N_\beta, B_\beta, \kappa_\beta, \tau_\beta\}$. Then α is a slant helix if and only if β is a slant helix.*

Proof. Let σ_N and σ_{N_β} be the geodesic curvatures of the principal normal curves of α and β , respectively. Then using the Theorem 3.9 we can easily see that

$$\sigma_{N_\beta} = -\frac{\kappa(1 + H^2)^{\frac{3}{2}}}{H} = -\sigma_N.$$

So, with the help of the Theorem 2.7 we complete the proof. \square

Theorem 3.12. *Let $\alpha : I \subset \mathbb{R} \rightarrow G$ be a parametrized Bertrand curve with curvature functions κ, τ and $\beta : \bar{I} \subset \mathbb{R} \rightarrow G$ be a Bertrand mate of the curve α with curvature functions κ_β, τ_β . Then α is a general helix if and only if β is a general helix.*

Proof. Let α be a helix. From Theorem 2.5, we have H is a constant function. Then using Theorem 3.9, we get

$$\frac{\tau_\beta - \tau_{G\beta}}{\kappa_\beta} = \frac{\lambda + \mu H}{\mu - \lambda H}. \quad (3.11)$$

Since H is constant function, the Eq. (3.11) is constant. So, β is a general helix.

Conversly, assume that β be a general helix. So, $\frac{\tau_\beta - \tau_{G\beta}}{\kappa_\beta} = \text{constant}$. From the Eq. (3.11) $c = \frac{\lambda + \mu H}{\mu - \lambda H} = \text{constant}$ and then $H = \frac{c\mu - \lambda}{\mu + \lambda c} = \text{constant}$. Consequently α is a general helix. Which completes the proof. \square

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